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WASTE CITRUS ACTIVATED SLUDGE AS A POULTRY FEED INGREDIENT

Richard H. Jones, et al

Winter Garden Citrus Products Cooperative

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16. ABSTRACT

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It is shown in this report that the inclusion of sludge in properly formulated diets up to 7.5 percent did not significantly affect poultry performance or meat or egg quality. The value of the sludge was calculated based on the reduction in feed ingredients resulting from the inclusion of sludge. It was found that the value of the recovered sludge significantly reduced the total cost of sludge handling.

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This report presents an evaluation of the potential of utilizing waste activated sludge as a poultry feed supplement. The sludge used in this study was obtained from an activated sludge process treating concentrated citrus waste containing no sanitary wastewater. The sludge was thickened, dewatered and dried using full-scale and pilot-scale equipment. The dried sludge was then analyzed for protein, fiber, amino acids, nutrients and moisture. Poultry feeds containing varying concentrations of sludge were prepared. Two experiments with broiler chicks, each of three weeks duration, one 8-week broiler study, and a six-month laying hen study were conducted to determine the effect of the inclusion of sludge in poultry diets on performance and quality.

It is shown in this report that the inclusion of sludge in properly formulated diets up to 7.5 percent did not significantly affect poultry performance or meat or egg quality. The value of the sludge was calculated based on the reduction in feed ingredients resulting from the inclusion of sludge. It was found that the value of the recovered sludge significantly reduced the total cost of sludge handling.

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Mr. Harold W. Thompson of the U. S. Environmental Protection Agency served as Project Officer and is acknowledged for his cooperation and assistance.

SECTION I

CONCLUSIONS

The activated sludge process is a viable treatment alternative for the citrus industry and its application can be expected to increase in the future. One of the major problems associated with the activated sludge process is the production of excess sludge which must be handled in some manner. The handling of excess sludge is both a technical difficulty and an economic burden.

It has been demonstrated through this study that waste activated sludge can be handled by a system consisting of gravity thickening and centrifugation. The unit cost of dewatering sludge in this manner, to a solids concentration of 8 percent, is approximately $119/kkg ($108/ton) of dry solids. This cost does not include the cost of final disposal which, for the Winter Garden Citrus Products Cooperative, is estimated to be $6/kkg ($5.45/ton) for land disposal.

One method of off-setting the cost of sludge dewatering and final disposal would be to develop a use for the sludge. It has been demonstrated through this study that the use of dried sludge as an ingredient in a properly formulated poultry diet may be a viable means of reducing the cost of sludge handling. In this study, dried activated sludge was included in the diets of broiler chicks and laying hens in amounts varying from 0.0 to 20.0 percent. Above levels of approximately 10 percent, the inclusion of sludge resulted in a significant depression in final body weight, feed efficiency and other performance factors. The addition of less than 10 percent sludge did not adversely affect poultry performance and, in fact, provided some improvement in performance.

The inclusion of dried sludge in poultry diets allowed for a reduction in the percentage of yellow corn, soybean meal and phosphate required,

while increasing the percentage requirement of animal fat and sulfur amino acids. The inclusion of 7.5 percent (by weight) dried sludge in a poultry diet resulted in a savings in feed ingredients valued at $8.00/kkg ($7.26/ton) of feed. Thus, the apparent value of the dried sludge was $107/kkg ($97/ton), while the cost of drying previously dewatered sludge was approximately $79/kkg ($72/ton). Thus, the cost of final disposal would be replaced by an apparent profit of $28/kkg ($25/ton).

The total cost of sludge handling has been shown to be approximately $119/kkg ($108/ton) for dewatering plus $6/kkg ($5.45/ton) for ultimate disposal by landfilling. Recovery of the sludge for poultry feed reduces the total cost of sludge handling by about 27 percent to $91/kkg ($83/ton). Because of the seasonal nature of the Florida citrus industry, these cost figures apply only to Winter Garden Citrus Products Cooperative or similar facilities.

SECTION II

RECOMMENDATIONS

It is recommended that further study be conducted with the objective of isolating the factor or factors which depressed poultry performance at higher sludge dietary levels. Additional work should be conducted to pursue the findings of pilot trials which indicated that sludge might have value as a pigment source for egg yolk coloration.

It is recommended that further study be conducted to develop improved sludge handling technology. Investigation of alternative sludge drying methods should be undertaken.

The use of dried sludge as a poultry feed ingredient should be recommended to poultry producers in order to provide a market for the sludge. Incentive should be provided to industry and poultry producers to encourage utilization of sludge as a feed ingredient.

SECTION III

INTRODUCTION

Since its discovery in 1914,[1] the activated sludge process has been utilized in a wide variety of applications; and, with increasingly stringent effluent limitations, the use of the activated sludge process can be expected to increase. In the Florida citrus industry, there are several biological treatment alternatives which are available to meet the effluent limitation requirements. However, for many citrus processors the lack of suitable land prohibits the use of alternatives other than the activated sludge process.

One of the major problems associated with this process is the production of excess activated sludge. The handling and disposal of excess activated sludge results in one of the largest operating expenses in the activated sludge process. The purpose of this project was to demonstrate a system for handling waste activated sludge and to study the potential of utilizing the recovered sludge as a poultry feed supplement, thereby reducing the financial burden of final sludge disposal.

SCOPE AND PURPOSE

The primary objective of this project was to demonstrate the potential of using waste activated sludge as a chicken feed supplement. This objective was to be accomplished by using waste activated sludge from an existing activated sludge system treating concentrated citrus processing waste containing no sanitary waste. The activated sludge was to be dewatered and dried by a system consisting of a gravity thickener, a centrifuge, and a rotary kiln dryer. The potential of using waste activated sludge as a chicken feed supplement was to be determined through actual chicken feeding studies, including evaluation of produce quality (both meat and egg) and post mortem examinations. This research was not designed to assay nutrients or determine biological availability, but rather to gain

basic information about what practical levels of sludge could be utilized, the level of toxicity, and taste impartation to meat or eggs.

BACKGROUND

This demonstration project was a supplement to a previous project funded by a grant from the U. S. Environmental Protection Agency.[2] The purpose of that grant was to demonstrate the use of the complete mix activated sludge process for treatment of citrus process wastes at the Winter Garden Citrus Products Cooperative (WGCP) citrus processing plant in Winter Garden, Florida. The resulting treatment system was the first approved system of its type in the State of Florida. It was designed to treat 88 l/sec (2.0 MGD) at an average BOD concentration of 2,000 mg/l and can consistently achieve a BOD reduction of 98 to 99 percent.

As with most activated sludge processes, one of the major costs of treating the WGCP wastewater is the cost of sludge handling. The complete mix system produces 0.5 to 0.6 kg TSS/kg BOD_5 removed per day.[3] At Winter Garden Citrus the production of total solids is 5,400 to 6,400 kg/day (6 to 7 tons/day) on a dry weight basis at the design loading rate. The original design for sludge handling consisted of sludge dewatering using a solid bowl, scroll type centrifuge followed by drying in existing rotary kiln dryers along with citrus peel. The citrus peel and dried sludge were then to be sold as a cattle feed supplement. The determination of the value of the sludge as an animal feed supplement was not part of the initial grant. Unfortunately, the centrifuge failed to operate properly causing the kiln dryers to become overloaded. This required that the portion of the waste sludge which could not be handled in the kiln dryers be disposed of by land spreading. Thus, the objective of this project was to determine the value of the sludge as a chicken feed additive and simultaneously develop a suitable sludge handling method for the Cooperative.

The program consisted of pilot testing two centrifuges, a solid bowl basket type and a disc type, in order to select a full-scale centrifuge.

A full-scale system was then operated consisting of a gravity thickener and a disc type centrifuge in order to dewater sludge prior to drying along with citrus peel in existing rotary kiln dryers. A pilot plant rotary kiln dryer and a sand bed were utilized to dry sludge for chicken feeding tests. The potential of the dried sludge as a chicken feed supplement was determined by a series of feeding tests conducted by the Department of Poultry Science at the University of Florida.

SECTION IV

EXPERIMENTAL EQUIPMENT AND PROCEDURES

This report describes two fundamentally different types of experimentation. One section is sludge recovery by thickening, dewatering, and drying. The second section of experimentation concerns the feeding of dried sludge to chickens. Obviously, the equipment, procedures, techniques and terminology for these two types of experimentation differ widely. For this reason, the materials and methods used will be described in two separate sections.

SLUDGE RECOVERY

The treatment system utilized at the WGCP is shown schematically in Figure 1. The pre-screened wastewater enters the aeration basins following nutrient addition and pH control. Nutrients are added in the form of phosphoric acid and anhydrous ammonia. The aeration basins are circular, concrete tanks, 44 meters (144 feet) in diameter with a side water depth of 3.6 meters (12 feet). Each tank, equipped with three 75 H.P. floating mechanical aerators, can be operated in series or parallel. Effluent from the aeration basins flows to a clarifier from which return sludge is pumped back into the influent pipe to the aeration basins. The supernatant liquor from the clarifier is either returned to the citrus processing plant for reuse as cooling water or discharged.

Excess activated sludge is pumped from the bottom of the clarifier to a gravity thickener from which supernatant is returned to the aeration basins, and thickened sludge is discharged to a sludge holding tank. The thickened sludge was then centrifuged, with the centrate returned to the aeration tanks.

The equipment used for sludge recovery in this study was all full-scale equipment with the exception of a pilot scale rotary kiln dryer and a pilot-scale flash evaporator. Sludge was thickened in a gravity thickener

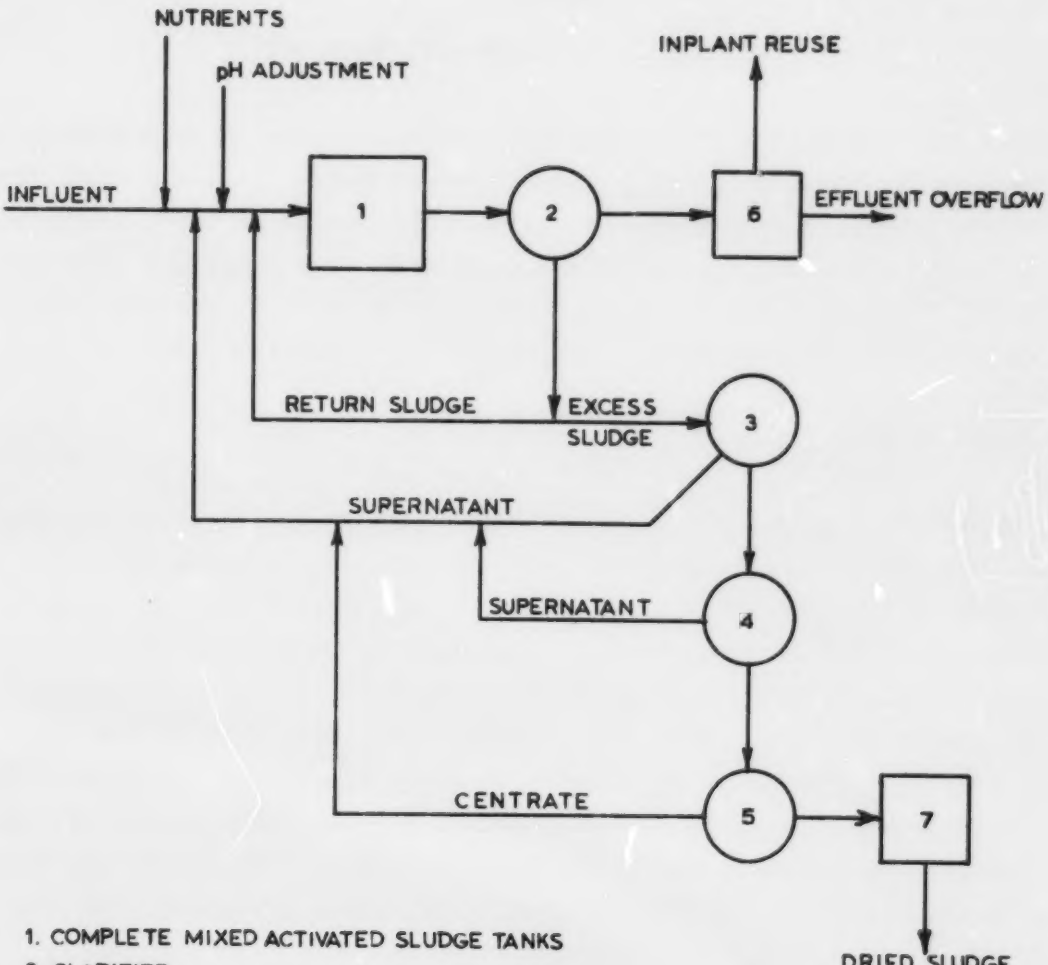

Figure 1. Wastewater treatment system

which had been converted from a lime treatment unit. The thickener has a 17-meter (55-foot) diameter and a side water depth of 4.6 meters (15 feet). Since the tank was originally designed as a lime treatment tank, the sludge rake mechanism was actually typical of a standard lime water softening mechanism. The thickened sludge was raked to a center trough and removed with a Moyno pump. Supernatant was returned to the activated sludge units while thickened sludge was pumped to a conical surge tank. Sludge was pumped with Moyno pumps from the surge tank to the subsequent dewatering units.

The thickener and surge tank were operated on a continuous basis as an integral part of the treatment system during the testing period. Thus, influent solids concentration and surface loading rate varied depending on the treatment plant operation. The only analyses performed on the thickened solids were total suspended and volatile suspended solids. These analyses were performed on-site in accordance with Standard Methods.[4]

The equipment used for dewatering was two types of centrifuges and a pilot-scale flash evaporator. The first type was a Fletcher Sharples basket centrifuge manufactured by the Pennwalt Corporation shown schematically in Figure 2. The unit tested was a production size unit, the 102 cm by 61 cm (40-inch by 24-inch) SST-900. This centrifuge was tested at various loading rates with and without polymer addition. The feed to the centrifuge and the centrate were analyzed on-site for suspended solids. The cake was analyzed for total solids.

The second centrifuge tested was a Westfalia disc type unit. The unit tested was a full-scale centrifuge. Figure 2 also illustrates the internal configuration of this type of centrifuge. The Westfalia unit was operated at various loading rates with and without polymer addition.

A pilot flash evaporator was tested to determine its efficiency for sludge thickening and to determine if it could replace the centrifugation process. The flash evaporator was a pilot-scale unit consisting

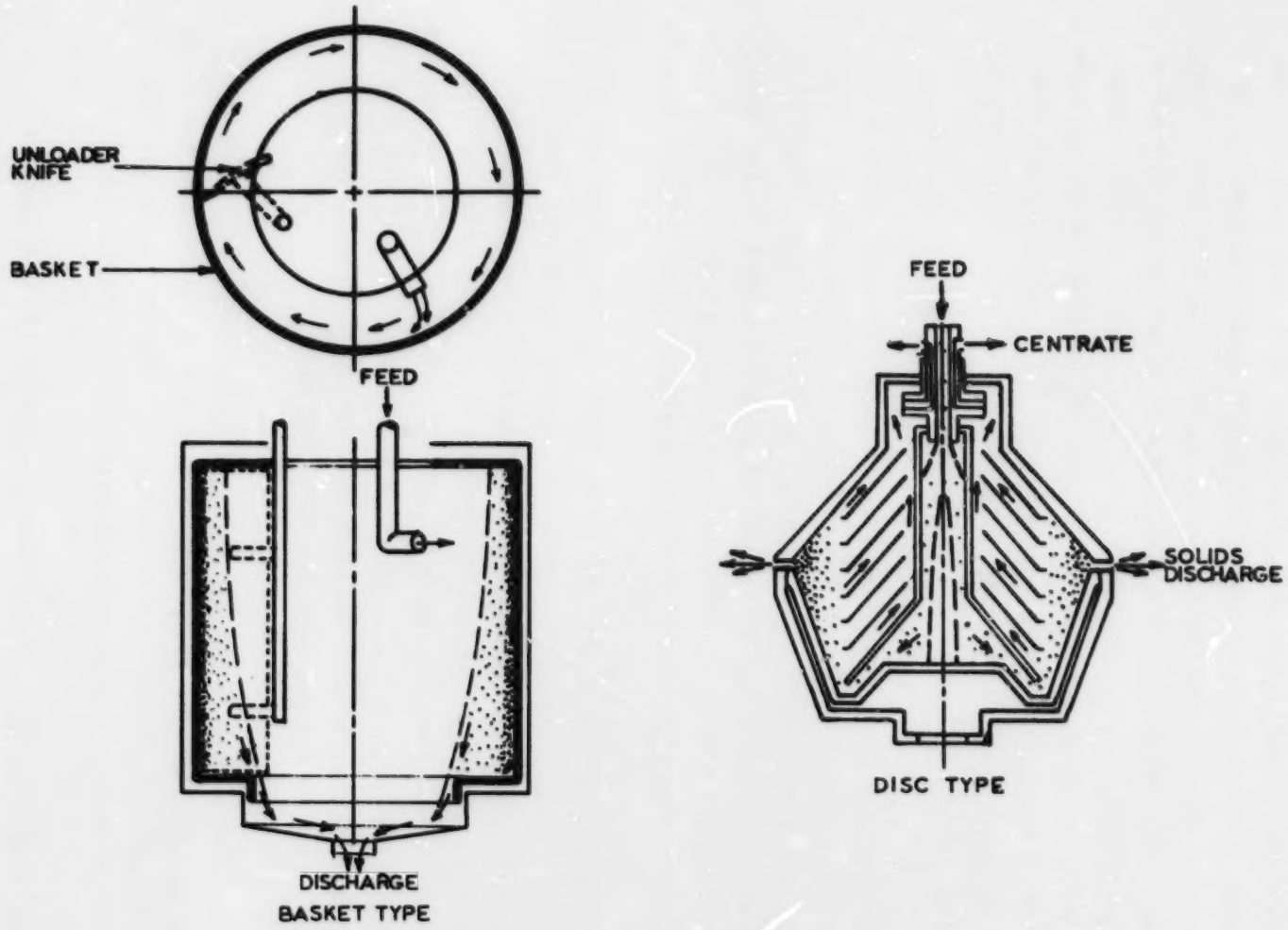

Figure 2. Schematic diagram of test centrifuges

of a propane gas fired torch, a rotary fan for heated air-sludge mixing prior to wet sludge-air separation in a separation chamber. The unit was also equipped with a product storage tank and a feed sludge holding tank. Sludge was recycled by the use of a rotary vane pump. Sludge was pumped from the sludge holding tank into the rotary fan. The hot air and sludge were mixed by the fan and blown into the separator. Exhaust gases were vented through the top of the separator and thickened material collected at the bottom.

After dewatering in a centrifuge, the sludge had to be dried to provide material for the feeding studies. Two methods of drying were tested--a rotary kiln dryer and sand beds. The rotary kiln was a pilot-scale three-pass drum dryer constructed of two concentric rotating drums inside a third stationary insulated drum. The overall dimensions of the drum were 76 cm (30 inches) in diameter and 1.8 meters (6 feet) long. Heat was supplied by a propane torch and the kiln was operated at 590°C (1100°F) to 760°C (1400°F) inlet temperature and 65°C (150°F) to 95°C (200°F) outlet temperature. The rotating drums were operated at 15 rpm, and the kiln was hand fed. Material transport within the kiln was achieved by sets of parallel longitudinal baffles attached inside all three drums. After the third pass in the dryer, the dried material was pulled into a two-stage, single fan cyclone and dropped into a collection bucket. Material fed into the dryer was maintained at 30 to 40 percent moisture by mixing with recycled dried material.

The sand beds used were conventional sludge drying beds located at the City of Winter Park's sewage treatment plant. Thickened sludge was placed on the beds and left until dried. The dried sludge was removed by hand. Extraneous sand was removed by a shaker screen.

POULTRY FEED

Prior to beginning the poultry feeding tests, a composite sample of the sludge produced via the above drying methods was analyzed to determine moisture, protein, crude fiber, calcium and phosphorus content. Amino

acid content was taken from the work of Hackler.[5] Metabolizable energy value was estimated. Based on this analysis, a series of diet compositions containing various levels of sludge were formulated, with the diets in each experiment containing equal levels of protein, calcium, phosphorus, total sulfur amino acids and metabolizable energy. The composition of each diet is presented in Section V.

The poultry feeding tests consisted of two series of broiler chick evaluations each of three weeks duration, a broiler study of eight weeks duration, and a six-month laying hen trial.

Broiler Chick Trials

The broiler chick trials were conducted in Petersime electrically heated battery brooders with raised wire floors. Four pens, each containing five male and five female broiler type chicks were used in each trial. Mortality was recorded on a daily basis and all birds were group weighed by sex at the end of the three-week test period. The specific diet compositions utilized are discussed in Section V.

Broiler Study

The broiler study was conducted over an eight-week period which is the standard growing period for commercial broilers. Twelve replicate floor pens, each containing 10 male and 10 female day-old broiler chicks, received each dietary treatment over the 56-day feeding period in three replications. The daily feed intake and final body weight of the birds was determined.

At the end of the eight-week feeding period, the individual groups were kept separate, sacrificed, and processed. A scalding temperature of 60°C for 40 seconds was used. For future identification, each pen of birds was wing banded as to sex and treatment following picking. The evicerated carcasses were then rapidly chilled to 5°C in ice slush and held six hours. The birds were graded as chilled carcasses following

the standards established by the USDA Poultry Grading Manual[6] for fleshing. Each bird was then individually packaged in 2-mil polyethylene bags (10 cm by 15 cm by 40 cm) and stored at -18°C.

The frozen carcasses were thawed overnight as needed in a walk-in refrigerator (6°C) and weighed prior to cooking. The carcasses were cooked, five to a pan, with breast up and two pans at a time in a conventional oven to an internal thigh temperature of 90°C. The internal temperature was measured by copper-constantan thermocouples inserted into four thigh muscles and attached to a Leeds & Northrup Speedomax H Potentiometer recorder. The carcasses were cooled to room temperature following cooking and weighed. The percent cooking loss was calculated. Analysis of variance was calculated to determine the significance of the dressed carcass weight according to sex and treatment.

Flavor, juiciness and texture of cooked light and dark meat were evaluated on five birds from each treatment-sex group for a total of 20 birds per day. The meat was evaluated by a semi-trained taste panel using a five point hedonic scale. Samples of dark meat, m. semitendinosus and m. semimembranosus, were excised together from the thigh at the coccygeal vertebra and caudal part of the ilium. The light meat sample was the large inner breast muscle, m. pectoralis superficialis (minor).

These muscles were removed only from the right side after the carcass had cooled to room temperature (27°C) and held for taste panel evaluation. The meat was cut into four pieces and the same relative section of meat was given to the same panel member for each of the four treatments on that day. The number of panelists available each day varied from 18 to 20. Each panelist was separated from others by dividers. Water was provided between samples. No attempt was made to alter the normal fluorescent room lighting. Analysis of variance was performed comparing differences between muscle, sex and treatment for flavor, juiciness and texture.

The remainder of the carcasses were removed from the refrigerator after 24 hours in order to determine tenderness using the Food Technology

Texture Press. The m. pectoralis superficialis (minor) was excised from the left side and wrapped to prevent moisture loss. All samples were allowed to reach room temperature and trimmed to a length of 6 cm and weighed to the nearest 0.1 gram. Each piece was placed perpendicular to the slots of the shear cell and the force recorded in 0.45 kg increments by a 136 kg force deformation ring. This force was converted to kg/gram of muscle tissue. An analysis of variance performed comparing significant differences between muscle, sex and treatment.

Laying Hen Trials

The last experiment involved the feeding of various levels of sludge to White Leghorn hens over a six-month period. As in the previous experiments, each feed was formulated to be isonitrogenous and isocaloric with each feed also containing equal levels of calcium, phosphorus and sulfur-containing amino acids. The specific diets are described in Section V. Eight replicate groups of five individually caged hens were assigned to each of the dietary treatments. Evaluation criteria were hen-day egg production, daily feed intake, feed required to produce a dozen eggs, mortality and egg weights.

Organoleptic evaluations were also conducted on the eggs produced during the above laying hen trials. Initially, two eggs (1 to 6 hours after lay) from each sludge treatment level were collected and broken open into plastic petri dishes, without breaking the yolks, and the yolk color scored by comparison with the Heiman-Carver color rotor. Yolk color measurements were subsequently made with a reflectance colorimeter, the IDL COLOR-EYE®. The COLOR-EYE values were converted to dominant wavelength, excitation, purity and luminosity which represent a mathematical description of the egg yolk color, all possible biases and human judgement being removed.

Four eggs (1- and 2-day old), held at 18.3°C and 75 percent room humidity, were selected from each replication and broken out to obtain a pooled

yolk sample. After removal of the majority of the albumen, each yolk was rolled on a dampened paper towel to remove all adhering albumen. The yolk was held over a beaker, the vitelline membrane ruptured and the yolk contents collected. The yolk material was hand-stirred, care being taken to keep the incorporation of air bubbles to a minimum. Lucite sample holders were used and analyses made on the IDL COLOR-EYE. Two additional color determinations were made at 10-day intervals using the above procedure.

Flavor comparisons were made on eggs collected from hens receiving the 0.0 percent (control) and the 20.0 percent (treatment) levels of citrus sludge. The eggs were held for five days at 18.3°C and 75 percent room humidity to permit optimum peelability, as these eggs were to be hard cooked by the cold water method as per Irmiter.[7] The paired-comparison test suggested by Dawson[8] et. al., was used to select the best sample. The eggs were hard cooked, cooled in ice water, peeled and quartered. Untrained panelists from the Poultry Science Department sampled three pairs each day with only one pair compared at a time. The eggs were served at room temperature on a 23-cm plate with a quarter-slice placed on the extreme left and a quarter-slice of the other (either the control or treatment) on the extreme right. Each pair of samples was placed on the plate before serving and coded to prevent the panelists from knowing beforehand the serving sequence. The panelists were asked to select separately the egg which had: 1) the darker colored yolk, 2) the greater degree of albumen off-flavor, and 3) the greater degree of yolk off-flavor. A minimum of 80-paired comparisons was necessary for the binomial distribution statistics of Dawson[8] and calculations performed as per Wilks.[9]

All statements of probability throughout the poultry feeding tests are based on the analysis of variance as described by Snedecor,[10] and significant differences being determined by the multiple range test of Duncan.[11]

SECTION V

RESULTS

The sludge recovery portion of this study was performed on-site at the WGCP citrus plant in Winter Garden, Florida. As a portion of the equipment being evaluated was full-scale equipment operated as an integral part of the treatment system, the operation of the activated sludge process during this period affected the results of the study. Therefore, the treatment plant operating data collected during the study period will be presented. Following the presentation of treatment plant operating data, the performance of the sludge recovery units will be presented. Finally, the results of the various poultry feeding tests will be presented.

OPERATION OF THE ACTIVATED SLUDGE PROCESS (1972-1973 SEASON)

The period of interest in this study is the 1972-1973 citrus processing season which lasted from December 1972 through August 1973. The chemical data collected during the season is tabulated in Table 1. The consistently high reduction in BOD and COD and the variation in influent concentration are also illustrated in Figure 3. Table 2 is a compilation of the average aeration tank operating data for the season.

The quantity of sludge wasted during the 1972-1973 season averaged approximately 1.8 to 2.7 kkg/day (2 to 3 tons/day). Table 3 shows typical chemical analyses of the waste activated sludge. The waste sludge volume varied from 246 to 734 M^3/day (65,000 to 194,000 gpd) with a clarifier underflow solids concentration of approximately 8,000 mg/l. The quantity of sludge wasted appears excessive because sludge was wasted to the sludge thickener and sludge holding tanks at a relatively constant rate. During periods when all of the waste sludge could not be handled by the centrifuge or kiln dryer, the excess overflowed the sludge holding tank back into the wastewater treatment plant.

Table 1. CHEMICAL ANALYSES FOR THE 1972-1973 OPERATING SEASON
(monthly averages)

Month	Average flow, M^3/day[a]	Sampling point	BOD, mg/l	COD, mg/l	pH[b]	PO_4, mg/l	NH_3, mg/l
December, 1972	4,540	Influent	630	1960	8.4	-	-
		Effluent	15	97	7.4	0.5	0.9
		% Reduction	97.6	95.0		-	-
January, 1973	6,060	Influent	980	3080	8.5	-	-
		Effluent	28	432	7.4	0.6	1.4
		% Reduction	97.1	86.0		-	-
February	5,680	Influent	1100	3310	8.2	-	-
		Effluent	20	159	7.0	2.2	0.9
		% Reduction	98.2	95.2		-	-
March	5,680	Influent	1040	3110	8.7	-	-
		Effluent	20	204	7.1	2.1	1.4
		% Reduction	98.1	93.4		-	-
April	5,300	Influent	930	2570	9.1	-	-
		Effluent	34	105	7.4	1.1	1.3
		% Reduction	96.2	96.0		-	-
May	6,810	Influent	480	2820	9.4	-	-
		Effluent	16	199	7.5	0.7	1.0
		% Reduction	96.5	93.0		-	-
June	6,060	Influent	530	2160	9.3	-	-
		Effluent	57	219	7.4	0.7	1.2
		% Reduction	89.2	89.9		-	-
July	4,540	Influent	600	1870	9.1	-	-
		Effluent	12	69	7.5	0.6	1.8
		% Reduction	98.0	96.3		-	-
August	3,790	Influent	400	1170	9.6	-	-
		Effluent	4	65	7.6	3.0	2.0
		% Reduction	99.0	94.4		-	-

[a] MGD = M^3/day (2.642×10^{-4})

[b] Median value

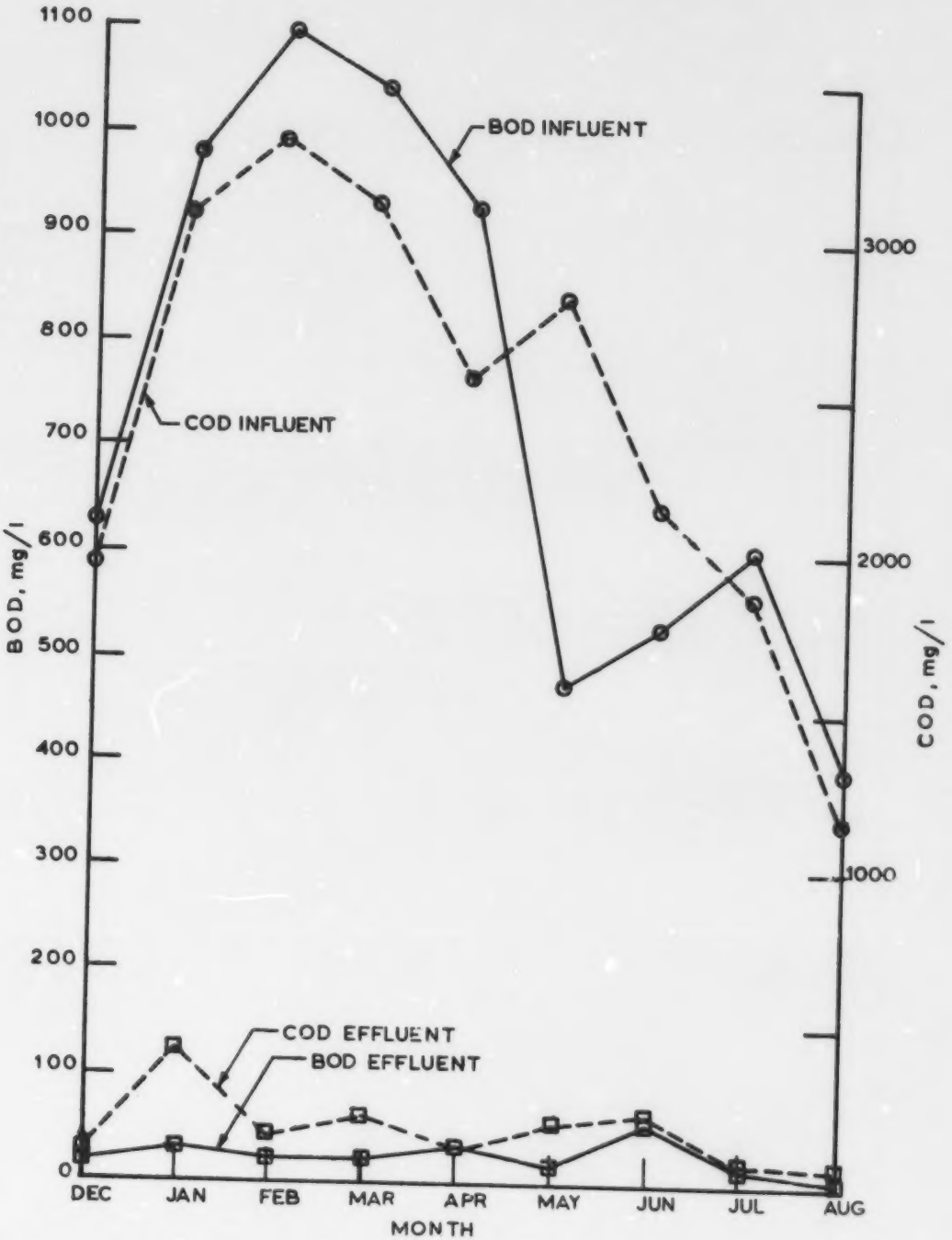

Figure 3. Influent and effluent BOD and COD, 1972-1973 season

Table 2. AVERAGE CHEMICAL ANALYSIS OF AERATION TANK, 1972-1973 OPERATING SEASON

Month	Mixed liquor suspended solids, mg/l	Dissolved oxygen, mg/l	pH[a]
December, 1972	3830	4.2	7.4
January, 1973	4140	1.8	7.4
February	5400	1.3	7.0
March	5400	1.2	7.1
April	4230	3.6	7.3
May	4250	2.4	7.4
June	3900	1.6	7.3
July	3960	2.5	7.5
August	3520	3.7	7.5

[a]Median value

Table 3. CHEMICAL ANALYSES OF WASTE ACTIVATED SLUDGE
(clarifier underflow)

Test[a] no.	Flow, M^3/day[b]	Total solids, mg/l	Volatile solids, mg/l	Waste sludge, kg TS/day[c]
1	708	6,390	5,490	4,520
2	708	7,320	6,440	5,180
3	708	8,750	7,800	6,200
4	708	8,130	7,250	5,760
5	246	7,290	6,430	1,790
6	492	9,870	8,890	4,860
7	708	10,970	9,670	7,770
8	708	9,360	8,190	6,630
9	708	6,670	5,600	4,720
10	708	9,040	---	6,400
11	246	2,360	---	582
12	708	7,250	6,260	5,130
13	708	7,560	6,540	5,350
14	708	7,940	6,850	5,620
15	674	7,660	---	5,160
16	367	6,770	---	2,480
17	674	8,700	7,600	5,860
18	674	8,420	8,070	5,680
19	674	8,160	7,780	5,500
20	674	11,290	10,110	7,610
21	613	16,290	14,720	9,980

Table 3 (continued). CHEMICAL ANALYSES OF WASTE ACTIVATED SLUDGE (clarifier underflow)

Test[a] no.	Flow, M^3/day[b]	Total solids, mg/l	Volatile solids, mg/l	Waste sludge, kg TS/day[c]
22	613	11,510	10,340	7,060
23	446	10,410	9,400	4,640
24	734	10,000	9,000	7,340
25	734	11,000	9,900	8,070
26	734	9,400	8,460	6,900
27	734	9,100	8,190	6,680
28	734	11,000	9,900	8,080
29	734	9,000	8,100	6,610
30	734	10,000	9,000	7,340
31	458	7,000	6,230	3,210
32	734	7,000	6,230	5,140
33	734	11,000	9,570	8,070
34	734	7,000	5,950	5,140
35	734	10,000	9,200	7,340
36	734	8,000	7,200	5,870
37	734	6,000	5,400	4,400
38	734	7,000	6,300	5,140

[a]Each test number represents a 24-hour sampling period

[b]gpd = M^3/day x 264.2

[c]lbs/day = kg/day x 2.20

SLUDGE RECOVERY

Various sludge recovery techniques were tested. In all cases the waste sludge was thickened prior to further recovery attempts. The efficiency of the thickener is shown in Table 4. The average total solids of the thickener underflow was 2.8 percent; however, with proper control a sludge concentration of 3.0 to 3.5 percent could be obtained. Assuming an influent and effluent total solids of 0.8 and 3.2 percent, respectively, the sludge thickener was able to decrease sludge volume by 75 percent.

Also shown in Table 4 is the effect on solids concentration of sludge storage in the holding tank. As can be seen, a well designed surge or holding tank can provide significant additional thickening.

The thickened sludge was dewatered by centrifugation, followed by rotary kiln drying, by drying without centrifugation, and by sand bed drying on open beds. Two centrifuges were tested at various feed rates and influent concentrations. Figure 4 shows the predicted capacity of a Fletcher-Sharples basket centrifuge. The SST-900 has a 102 cm bowl. Figure 4 was developed from data collected through the operation of an SST-900 at WGCP. The solids in the cake varied from approximately 7 to 10 percent depending upon the feed rate to the centrifuge.

Table 5 shows the results of 37 different tests using a Westfalia disc type centrifuge. Tests 1 through 31 were conducted without polymer and tests 32 through 37 were conducted with the addition of polymer (Hercofloc). The main effect of polymer addition was to increase the percent solids recovery; but it had little effect on cake dryness. At an average feed rate of 29 l/min (7.6 gpm) and a feed solids of 1.9 percent, the disc centrifuge was capable of producing a cake of approximately 7.2 percent solids with an 87 percent recovery efficiency.

As can be seen both types of centrifuge produced good recovery of activated sludge. Based on these results and in consideration of other

Table 4. CHEMICAL ANALYSES OF SLUDGE THICKENER UNDERFLOW AND SLUDGE SURGE TANK UNDERFLOW
(percent)

Test[a] no.	Thickener Underflow		Sludge Surge Tank Underflow	
	Total solids	Volatile solids	Total solids	Volatile solids
1	1.2	0.9	1.7	1.4
2	2.2	1.9	2.4	2.1
3	2.7	2.5	2.8	2.5
4	1.7	1.5	4.0	3.0
5	1.4	1.2	2.0	1.8
6	1.2	0.7	1.6	1.2
7	1.1	0.8	1.9	1.7
8	1.6	1.3	2.5	2.2
9	2.9	2.6	2.8	2.5
10	2.9	-	1.5	-
11	2.4	-	3.3	-
12	2.6	2.3	2.5	2.1
13	2.9	2.5	3.0	2.6
14	2.5	2.2	4.1	3.7
15	2.6	2.2	2.8	2.5
16	3.5	-	3.5	-
17	4.2	-	3.7	3.2
18	3.5	3.1	-	-
19	3.7	3.1	-	-

Table 4 (continued). CHEMICAL ANALYSES OF SLUDGE THICKENER UNDERFLOW AND SLUDGE SURGE TANK UNDERFLOW
(percent)

Test[a] no.	Thickener Underflow		Sludge Surge Tank Underflow	
	Total solids	Volatile solids	Total solids	Volatile solids
20	4.4	3.9	-	-
21	3.7	3.1	-	-
22	2.8	2.6	-	-
23	3.0	2.6	-	-
24	3.9	3.1	-	-
25	3.1	2.7	-	-
26	3.0	2.7	-	-
27	2.3	2.1	-	-
28	3.2	2.9	-	-
29	3.9	3.5	-	-
30	3.0	2.7	-	-
31	3.0	2.7	-	-
32	3.1	2.5	-	-
33	3.5	3.1	-	-
34	3.7	3.3	-	-
35	2.6	2.3	-	-
36	2.6	2.3	-	-

[a]Each test number represents a 24-hour composite sample

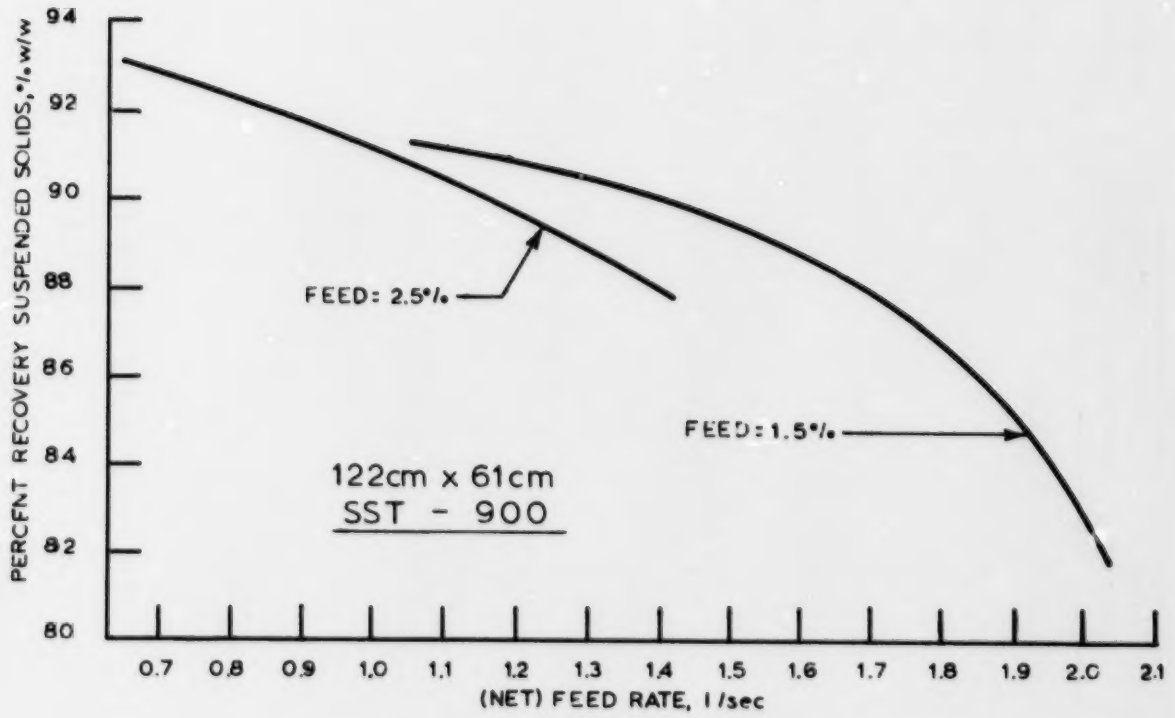

Figure 4. Percent recovery versus feed rate for a basket centrifuge (SST-900)

Table 5. TYPICAL RESULTS FOR THE WESTFALIA CENTRIFUGE

Test[a] no.	Feed rate, l/min[b]	Total Solids			Recovery, percent
		Feed, percent	Cake, percent	Effluent, percent	
1	34	1.2	7.6	0.14	89
2	34	1.2	7.7	0.12	90
3	34	1.2	5.5	0.12	90
4	34	1.2	8.2	0.23	81
5	21	0.9	8.1	0.12	86
6	21	0.9	5.9	0.12	86
7	21	1.4	9.7	0.29	80
8	21	1.4	8.4	0.11	92
9	57	1.4	6.4	0.14	90
10	57	1.4	6.8	0.18	87
11	34	2.2	8.2	0.72	67
12	34	2.2	6.9	0.19	92
13	34	2.2	7.6	0.37	83
14	-	-	-	-	-
15	19	2.2	9.2	0.14	94
16	19	2.2	7.4	0.07	97
17	19	2.4	8.7	0.08	97
18	19	2.4	8.3	0.11	96
19	23	2.4	8.1	0.61	75
20	23	2.4	9.0	0.52	79

Table 5 (continued). TYPICAL RESULTS FOR THE WESTFALIA CENTRIFUGE

Test[a] no.	Feed rate, l/min[b]	Total Solids			Recovery, percent
		Feed, percent	Cake, percent	Effluent, percent	
21	34	2.3	6.8	0.13	94
22	30	2.1	7.2	0.48	77
23	17	2.1	6.9	0.29	86
24	30	1.9	6.3	0.25	87
25	26	1.9	6.4	0.24	88
26	17	2.2	5.5	0.15	93
27	30	2.2	7.0	0.27	88
28	30	2.2	7.2	0.78	65
29	30	2.6	6.0	1.00	62
30	26	2.1	5.7	0.40	82
31	28	2.2	6.4	0.12	95
32	26	2.2	6.3	0.10	96
33	26	1.5	5.7	0.08	95
34	26	2.4	6.6	0.13	94
35	30	2.4	6.2	0.14	94
36	30	2.2	6.7	0.12	95
37	28	2.2	7.1	0.11	95

[a]Test numbers 1-33 with "open foot," 34-37 with "closed foot"
Test numbers 32-35 with 2.5 gms Hercofloc/kg dry solids
Test numbers 33-36 with 5.0 gms Hercofloc/kg dry solids

[b]gpm = l/min x 0.2642

factors, a full-scale Westfalia centrifuge was installed to operate full-time for sludge recovery. The factor influencing this choice was WGCP's previous experience with a solid bowl centrifuge which was not favorable. If the Westfalia unit failed to perform adequately for sludge recovery, it could be used in the oil mill for liquid-liquid separation, whereas the basket centrifuge would have no such application. The engineer's recommendation was against the use of the Westfalia unit because of the known effects of abrasive materials on the discs. No provision for grit removal was available in the activated sludge plant; therefore, quantities of sand resulting from the fruit washing operation found their way into the waste sludge. Sand had an abrasive effect on various parts of the disc centrifuge resulting in the centrifuge having to be taken out of service for repair. Unless sand or other abrasive material is removed from the waste sludge, it is questionable if this type machine can be utilized for sludge dewatering.

In order to provide a dry material for the chicken feeding studies and to provide needed operational data on sludge drying, a pilot rotary kiln dryer was tested. Rotary kiln dryers cannot function on a feed with as low a solids content as results from the gravity sludge thickener or the centrifuge. Therefore, it was necessary to recycle dried sludge to mix with the feed sludge to maintain an input solids content of approximately 40 percent.

Table 6 shows the results of 20 separate pilot plant "runs" using the rotary kiln dryer. Each run represents a successful operating day when the pilot plant was kept in continuous operation from 10 to 12 hours. There were numerous days that either mechanical failure or weather conditions (the plant was not covered) required a "run" to be terminated.

In an attempt to increase the production rate of the pilot plant kiln dryer, a pilot plant flash evaporator was installed to help remove a portion of the water from the gravity thickened sludge. Table 7 shows typical results obtained by drying sludge in the flash evaporator.

Table 6. PILOT PLANT KILN DATA

Run no.	Temperature, °C		Total solids, percent		Total volatile solids, percent		Cake produced, kg
	Inlet	Outlet	Influent	Cake	Influent	Cake	
1	650-760	66-79	3.5	74	—	—	6.4
2	650-760	66-79	4.2	89	89	74	3.2
3	650-760	74-85	2.6	90	90	74	4.5
4	650-760	80-93	2.3	94	90	75	1.8
5	590-700	80-93	3.3	94	90	66	2.3
6	590-700	80-93	3.2	91	86	72	3.6
7	590-700	80-93	3.2	92	92	70	2.7
8	590-700	80-93	4.9	92	93	69	2.3
9	590-700	80-93	3.7	93	91	69	1.8
10	650-700	80-93	3.8	93	84	69	1.8
11	650-700	80-93	3.6	95	96	73	1.8
12	650-700	80-93	2.4	98	86	75	0.9
13	650-700	80-93	2.6	98	93	70	1.4
14	590-650	80-93	4.8	96	92	71	1.8
15	590-650	80-93	3.9	94	87	69	1.8
16	590-650	80-93	4.8	92	90	70	1.8
17	590-650	80-93	4.6	95	88	76	1.8
18	620-650	80-93	6.5	95	91	79	0.9
19	540-650	80-93	4.6	96	87	76	3.2
20	590-650	80-93	5.8	94	90	77	2.3

Table 7. PILOT PLANT FLASH EVAPORATOR DATA

Run no.	Total solids, percent		Total volatile solids, percent	
	Inlet	Outlet	Inlet	Outlet
1	3.4	4.6	-	-
2	3.4	4.6	-	-
3	3.3	5.8	-	-
4	2.2	4.8	98	95
5	2.5	4.6	97	95
6	2.9	6.5	97	94

POULTRY FEEDING STUDIES

In order to evaluate the potential of waste activated sludge as a poultry feed supplement, three experiments were conducted. The experimentation consisted of two short-term chick trials, an eight-week broiler study, and a six-month feeding period with laying hens.

Prior to beginning these studies, the basic nutrient composition of the material was determined and is presented in Table 8. On an analytical basis, the dried sludge appears to be a good source of protein and phosphorus. It also contains substantial quantities of lysine and the sulfur containing amino acids--methionine and cystine. These are the amino acids which are normally in shortest supply in poultry feeds where corn and soybean meal are the staple ingredients. The relatively high level of fiber was of concern since chickens do not have the enzymes necessary to digest fiber. The metabolizable energy value which is estimated is approximately one-half that found in yellow corn.

Table 8. COMPOSITION OF DRIED ACTIVATED SLUDGE

Ingredient	Percent
Moisture	6.30
Protein	38.6
Crude fiber	12.6
Calcium	1.49
Phosphorus	1.59
Methionine[a]	0.50
Cystine[a]	0.20
Lysine[a]	1.30
Metabolizable calories/kilogram[b]	1760

[a]These values taken from Hackler[5]

[b]Estimate based on chemical analysis of sludge (protein, fat and NFE multiplied by appropriate calories/kg)

Broiler Chick Studies

The first two experiments were conducted in electrically heated battery brooders with raised wire floors to prevent fecal recycling. In each of the two experiments four replicate pens, each containing five male and five female day-old broiler type chicks, received dietary treatments consisting of various levels of sludge for a three-week feeding period. In the first experiment the birds received diets containing 0, 2.5, 5, 10, 15 or 20 percent sludge. The diets were composed primarily of yellow corn and soybean meal in combination with other ingredients commonly employed in poultry feeding. These diets and their composition are shown in Table 9.

All of the diets in the series were calculated to contain 23 percent protein, 1.1 percent calcium, 0.755 percent total phosphorus, 0.88 percent total sulfur amino acids, and 3,012 kilocalories of metabolizable

Table 9. COMPOSITION OF BASAL AND SLUDGE DIETS

Ingredient	Basal %	Sludge			
		2.5 %	5.0 %	10.0 %	20.0 %
Yellow corn	54.97	53.81	52.71	50.40	45.94
Soybean meal (48.5 percent)	36.50	34.71	32.87	29.28	21.98
Alfalfa meal (20 percent)	2.50	2.50	2.50	2.50	2.50
Sludge	0.00	2.50	5.00	10.00	20.00
Ground limestone (38 percent Ca)	0.74	0.79	0.82	0.89	1.05
Defluorinated phosphate (18 percent P, 32 percent Ca)	2.11	1.95	1.81	1.52	0.92
Iodized salt	0.40	0.40	0.40	0.40	0.40
Vitamin pre-mix[a]	0.50	0.50	0.50	0.50	0.50
Animal fat	2.15	2.70	3.23	4.33	6.47
DL-methionine	0.13	0.14	0.16	0.18	0.25

[a]Supplied per kilogram of diet: 6,600 I.U. vitamin A; 2,200 I.C.U. vitamin D_3; 499.4 mg choline chloride; 39.6 mg niacin; 13.2 mg pantothenic acid; 4.4 mg riboflavin; 2.2 mg menadione dimethyl-pyrimidinol bisulfite; 0.125 mg ethoxyquin; and 22 µg vitamin B_{12}

energy per kilogram. The inclusion of citrus sludge allowed for corresponding decreases in the amounts of yellow corn, soybean meal and defluorinated phosphate necessary to maintain equivalent diets; however, large increases in the amounts of animal fat and DL-methionine were required in order to maintain energy and sulfur amino acid levels.

Since previous work[12] has indicated that sludge tends to cause the destruction of unstabilized vitamin D sources, a supplemental level of 2,200 International Chick Units of vitamin D_3 per kilogram of diet was employed. This level of fortification was approximately 10 times greater than the requirement level of the starting chick as defined by the National Research Council.[13]

As previously mentioned, the chick performance tests were performed in two short-term experimental phases. The chick performance data for Experiment 1 are shown in Table 10. The daily consumption of feed did not vary significantly with different levels of sludge. However, the efficiency of the feed did vary significantly. Feed efficiency is measured as grams of feed consumed per gram of body weight and, obviously, the best efficiency is the least ratio of feed to final body weight. In Experiment 1, the best efficiency was obtained at the 2.5 and 5.0 percent sludge levels, and the inclusion of sludge up to 10 percent in the chicks' diet did not significantly affect the feed efficiency. The feed efficiency value for birds fed a diet containing 15 percent sludge was not significantly different from the value for the 10 percent sludge diet, but was different from values obtained for all other diets. Birds receiving a diet containing 20 percent sludge had a feed efficiency significantly lower than all other treatments or, in other words, a feed to body weight ratio significantly higher than any other sludge treatment level.

The final body weight for the broiler chicks in Experiment 1 at the end of the three week test is also given in Table 10. As can be seen, there was a trend to lower final body weight at higher sludge levels. The inclusion of sludge at levels above 10 percent resulted in a significant

Table 10. CHICK PERFORMANCE DATA (Experiment 1)

Treatment, percent sludge	Feed/bird/day, grams/day	Feed/body weight[a]	Body weight,[a] grams
0.0	30.4	1.48^{A}	411^{AB}
2.5	29.6	1.45^{A}	413^{A}
5.0	29.6	1.45^{A}	409^{ABC}
10.0	30.5	1.51^{AB}	403^{ABCD}
15.0	31.0	1.59^{B}	390^{CD}
20.0	31.6	1.74^{C}	365^{E}

[a]Means without common letters are significantly different according to Duncan's multiple range test ($P < 0.05$)

difference in final body weight. The 20.0 percent level of sludge resulted in a final body weight significantly lighter than that obtained at any other level of sludge treatment.

From the data obtained in the first experiment it was evident that some change in treatments should be made before the next study was initiated. It was felt that the growth depression associated with the 20 percent sludge diet might have been due to the low availability of sulfur amino acids, or because the dietary lysine level was slightly below the National Research Council's suggested requirement. Therefore, in the second experiment the amounts of methionine and lysine supplied in the first experiment by the inclusion of 20 percent citrus sludge were added back to this diet in purified form, resulting in total supplemental levels of 0.38 percent methionine and 0.26 percent lysine. Thus, the dietary treatments of the second experiment consisted of 0, 2.5, 5, 10, or 20 percent sludge, with a sixth treatment of 20 percent sludge plus additional methionine and lysine. The latter diet will subsequently be referred to as the "20 percent plus" diet. As in the first experiment,

all but the "20 percent plus" diet were calculated to be isonitrogenous, isocaloric and meet all other requirements of the starting chick.

Table 11 presents the results of the second experiment with broiler chicks. As in the first three-week experiment, no significant difference in daily feed intake values resulted at any of the sludge levels tested. Feed efficiency did not differ significantly from the basal diet up to the inclusion of 5.0 percent dried sludge in the chicks' diet. Also, efficiency values for birds receiving diets containing 10, 20 or the "20 percent plus" diets did not differ significantly. From a numerical standpoint, it appeared that levels in excess of 5 percent sludge adversely affected feed efficiency.

Table 11. CHICK PERFORMANCE DATA (Experiment 2)

Treatment, percent sludge	Feed/bird/day, grams/day	Feed/body weight[a]	Body weight,[a] grams
0.0	35.3	1.64^{ABC}	455^{AB}
2.5	35.6	1.62^{A}	460^{AB}
5.0	37.3	1.66^{ABC}	472^{A}
10.0	34.4	1.75^{CD}	414^{C}
20.0	37.2	1.83^{D}	423^{C}
20.0 + Lysine & Methionine	35.3	1.74^{BCD}	425^{C}

[a]Means without common letters are significantly different ($P < 0.05$) according to Duncan's multiple range test

As shown in Table 11, there were no significant differences among the body weights of birds receiving either 0, 2.5 or 5 percent sludge; however, there was some trend towards parallel sludge and body weight increases for this group. Weights of treatment groups receiving above 5

percent sludge were all significantly below those of the lower sludge levels previously mentioned, but did not differ statistically from each other.

Mortality was not a factor in either experiment, as mortality records indicated that only one bird died in each trial. Throughout all experiments, the addition of sludge had no effect upon feed or dropping condition, other than to impart a dark color to both.

These data indicate that levels of between 5 and 10 percent sludge could be included in the diet of starting broiler chicks without adversely affecting growth or other performance criteria. The exact level tolerated would be dependent upon feed intake, as evidenced by the fact that birds of the second experiment tolerated a lower dietary percentage because their feed intake was higher than that of the birds utilized in the first experiment.

Broiler Studies

The next phase of experimentation was a broiler study of eight weeks duration in which broiler chicks were fed a control diet supplemented with either 2.5, 5.0 or 10 percent citrus sludge. The diets used were identical in composition to those shown for previous experiments, with the exception of the inclusion of 0.05 percent Amprol, a coccidiostat, in place of an equal amount of yellow corn. Table 12 presents the final body weight, feed consumption and feed efficiency of the broilers at the various sludge levels. In this experiment there was no significant difference in final body weights at any level of sludge treatment. However, as seen in the chick trials, body weights tended to increase through the 5 percent level of supplementation with the weights of the birds receiving 10 percent sludge being somewhat lower than those of controls.

Daily feed intake values were rather variable within this experiment, but increased levels of intake did appear to be correlated with dietary

Table 12. DATA FROM BROILER STUDY

Sludge, percent	Body weight, grams	Feed/bird/day,[a] grams/day	Feed/body weight
0.0	1750	66^{AB}	2.16
2.5	1772	63^{A}	2.08
5.0	1800	67^{B}	2.16
10.0	1732	68^{B}	2.25

[a]Means without common letters are significantly different ($P < 0.05$) according to Duncan's multiple range test

sludge content. Again, feed required per unit of body weight was not significantly influenced by treatment and, in general, these values reflected the trends of body weight and daily feed intake. These data tend to substantiate other trials in that a level of sludge somewhere between 5 and 10 percent appeared to support best performance.

In addition to determining feed efficiency levels for the broilers, taste panel evaluations of muscle tissue from these birds were also conducted. At the end of the eight-week feeding study, the birds were sacrificed, picked and frozen as previously described. The frozen carcasses were thawed overnight and weighed prior to cooking. The average dressed carcass weights are shown in Table 13. A significant difference in weights was observed between sexes at the 0.01 level of significance. However, there were no significant effects attributable to sludge levels.

The carcasses were then cooked in a conventional oven to an internal thigh temperature of 90°C. The cooked birds were then weighed to determine the percent cooking loss. No significant difference in cooking loss due to sludge treatment levels was found. The mean cooking loss was 25.57 percent and the standard deviation was 3.87 percent.

Table 13. AVERAGE DRESSED CARCASS WEIGHT FOR BROILERS FED VARIOUS DIETARY LEVELS OF SLUDGE

Sludge, percent	Dressed carcass weight, grams	
	Male	Female
Basal	1228	984
2.5	1126	1042
5.0	1238	1024
10.0	1212	970
Average[a]	1202	1005

[a]Overall average, 1102; standard deviation, 103

Flavor, juiciness and texture of cooked light and dark meat were evaluated by a semi-trained taste panel. Palatability was graded on a five-point hedonic scale. While there was a significant difference in preference between dark and white meat, as shown in Table 14, there was no significant difference due to sludge treatment level. There was also no significant difference in shear strength in the muscle tissue of birds fed different levels of sludge.

Laying Hen Studies

The last phase of experimentation involved the feeding of 0, 2.5, 5.0, 7.5 or 20 percent sludge to laying hens over a six-month period. The composition of the basal diet and the diet containing the 20 percent sludge addition are shown in Table 15.

These sludge additions were made while maintaining a constant level of protein at 15 percent, calcium at 3.25 percent, 0.65 percent phosphorus, 0.59 percent sulfur containing amino acids, and 2,860 kilocalories of metabolizable energy per kilogram of diet. As noted before, sludge

Table 14. AVERAGE AND MEAN PALATABILITY SCORES OF DARK AND WHITE MEAT FROM COOKED MALE AND FEMALE BROILERS[a]

Sludge, percent	Type meat	Flavor	Juiciness	Texture	Mean
Basal	Dark	0.58	0.33	0.32	0.42
	Light	0.85	-0.08	0.89	0.56
2.5	Dark	0.57	0.33	0.38	0.43
	Light	0.85	-0.12	0.84	0.52
5.0	Dark	0.63	0.40	0.64	0.56
	Light	0.84	-0.15	0.81	0.50
10.0	Dark	0.51	0.32	0.43	0.42
	Light	0.96	0.04	0.84	0.61

[a]-2 is for very unacceptable, dry or tough and +2 is for very acceptable, moist or tender

Table 15. LAYING HEN SLUDGE DIET COMPOSITION

Ingredient	Percent	
	Basal	20% sludge
Yellow corn	66.50	58.00
Soybean meal (48.5%)	17.96	3.34
Alfalfa meal (20%)	2.50	2.50
Sludge	--	20.00
Limestone (38% Ca)	6.77	6.98
Defluorinated PO_4 (18% P, 32% Ca)	1.94	0.80
Iodized salt	0.40	0.40
Microingredients	0.50	0.50
Animal fat	1.10	5.22
DL-Methionine	0.06	0.17
Filler	2.27	2.09

additions allowed for the removal of yellow corn, almost all of the soybean meal, and a large portion of the defluorinated phosphate, with corresponding increases of animal fat and DL-methionine. Evaluation criteria included egg production, daily feed intake, feed required to produce a dozen eggs, mortality and egg measurements of average weight, specific gravity and Haugh units. In addition, organoleptic evaluations were conducted on the eggs produced and the differences in yolk color evaluated. Eight replicate groups of White Leghorn hens held in individual laying cages were assigned to each dietary treatment through 7.5 percent sludge. Four replicate groups received the 20 percent level.

Egg production was not affected by the addition of levels of sludge through 7.5 percent as shown in Table 16; however, the 20 percent level did cause a significant depression of egg production.

Table 16. AVERAGE LAYING HEN PERFORMANCE (6 months)

Treatment, percent sludge	Average egg production,[a] percent	Egg weight,[a] grams
0.0	69.61^{A}	62.9^{A}
2.5	68.32^{A}	63.4^{A}
5.0	67.01^{A}	63.6^{A}
7.5	69.21^{A}	63.3^{A}
20.0	42.12^{B}	59.0^{B}

[a]Means without common letters are significantly different ($P < 0.05$) according to Duncan's multiple range test

The average weight of eggs produced followed exactly the same trends as egg production.

There was no significant effect upon daily feed intake until the 20 percent level of sludge was reached, as shown in Table 17.

Table 17. AVERAGE LAYING HEN PERFORMANCE (6 months)

Treatment, percent sludge	Feed/bird/day,[a] grams/day	Feed/dozen eggs,[a] kilograms
0.0	113^{A}	2.00^{A}
2.5	109^{A}	1.98^{A}
5.0	114^{A}	2.13^{A}
7.5	112^{A}	2.01^{A}
20.0	92^{B}	2.86^{B}

[a]Means without common letters are significantly different ($P < 0.05$) according to Duncan's multiple range test

This feed intake trend is very definitely related to egg production rate; however, it is very difficult to determine whether the intake depression resulted in lowered production or whether the lowered production resulted in reduced feed intake. As expected, the amount of feed required to produce a dozen eggs was also a function of the egg production and feed intake trend.

Specific gravity is a measurement of eggshell quality made by moving each egg through a graded series of salt solution. No significant differences due to treatment were found, as illustrated in Table 18.

Table 18. AVERAGE LAYING HEN PERFORMANCE (6 months)

Treatment, percent sludge	Specific gravity	Haugh units[a]
0.0	1.0792	64.3^{A}
2.5	1.0801	67.4^{AB}
5.0	1.0787	69.4^{B}
7.5	1.0780	68.9^{B}
20.0	1.0781	82.0^{C}

[a]Means without common letters are significantly different ($P < 0.05$) according to Duncan's multiple range test

Haugh units are a measure of interior egg quality arrived at through an integration of egg weight and albumen height. A trend towards improving Haugh unit scores is seen as the level of sludge increased through 7.5 percent. The scores of eggs from hens receiving either 5 or 7.5 percent citrus sludge were significantly better than those of control birds. The extremely high value from hens receiving 20 percent sludge was anticipated since interior egg quality is normally inversely related to the bird's level of egg production.

Proper egg yolk color is a very important commercial consideration and, due to the possibility of off-flavors developing from the feeding of citrus sludge, a further investigation of the effect of sludge upon these parameters was initiated.

Initially, two eggs from each treatment group were collected and broken open into plastic petri dishes, without breaking the yolks, and the yolk color scored by comparison with a color rotor which carries a graded series of standard color spots. The scores ranged from 12 for the yolks of eggs from control hens to 18 for those receiving 20 percent citrus sludge (Table 19). This score increase represents a definite increase of yolk color intensity, with a higher number indicating the darker color.

Table 19. INTERRELATIONSHIP OF DIETARY SLUDGE AND HEIMAN-CARVER COLOR ROTOR NUMBERS

Sludge, percent	Heiman-Carver color rotor numbers
0.0	12
2.5	14
5.0	15
7.5	16
20.0	18

Subsequent yolk color measurements were made with reflectance colorimeter, the IDL COLOR-EYE®. The COLOR-EYE values represent a mathematical description of egg yolk color with all possible biases and human judgement being received. For this evaluation, eggs were collected from hens in four replications of each dietary treatment. Four eggs from each replication were then broken out to obtain a pooled yolk sample and prepared for COLOR-EYE evaluation. The results of these COLOR-EYE determinations are summarized in Table 20.

Table 20. COLOR CHARACTERISTICS OF EGG YOLK

Sludge, percent	Dominant wavelength, nm
0.0	578.5
2.5	579.3
5.0	579.5
7.5	580.8
20.0	583.5

As the level of dietary citrus sludge increased the dominant wavelength, which is the color or hue of the egg yolk, also increased. This numerical improvement represents a change in color from yellow to a yellowish-orange hue. Increasing sludge levels dictated the removal of both yellow corn and soybean meal. Yellow corn is normally a prime source of egg yolk coloration. The removal of 12.8 percent yellow corn from the basal diet in order to formulate the 20 percent level of citrus sludge resulted in a lower contribution of yellow corn to dietary pigmentation; however, the addition of citrus sludge more than compensated for this reduction.

Flavor and color comparisons were also made by untrained taste panelists from the Department of Poultry Science, University of Florida, on eggs collected from hens receiving either the control or the 20 percent sludge

diet. The eggs were held for five days to permit optimum peelability and then hard-cooked for sampling. A paired-comparison test was used with each panelist sampling three pairs each day, but only one pair at a time. They were asked to select separately the egg which had the darker colored yolk, the greater degree of albumen off-flavor and the greater degree of yolk off-flavor. The evaluation of 86 separate pairs (Table 21) showed that a level of 20 percent citrus sludge resulted in significantly darker yolks than the control.

Table 21. TASTE PANEL EVALUATION OF EGGS FROM CONTROL AND 20.0 PERCENT SLUDGE DIETS

Attribute	Preference		Significant difference[a]
	Control	Sludge	
Yolk color	5	81	yes
Yolk flavor	42	44	no
Albumen flavor	40	46	no

[a]Acceptance range (52.3 - 33.8) at $P < 0.05$

Eighty-one of the 86 panelists found the citrus sludge eggs to have a darker yolk color, which is well outside of the acceptable range of 33 to 52. No significant off-flavor was detected for either the albumen or the yolk, as these two parameters fall within the acceptable range.

SECTION VI

DISCUSSION

In Section V, the data collected during this study were presented and briefly discussed. The purpose of this section is to discuss the significant results of this study, to develop a prototype design for the recovery of sludge for subsequent use as a poultry feed, and to discuss the value of the sludge as a poultry feed supplement.

DISCUSSION OF THE RESULTS

The primary objectives of this project were to determine the value of waste activated sludge as a poultry feed supplement and to determine the feasibility of recovering sludge for this purpose. In order to accomplish these objectives, the value of the sludge had to first be determined through feeding tests. Subsequently, it had to be determined whether or not it is possible to thicken, dewater, and dry activated sludge at a cost commensurate with the value of the sludge as a feed material.

The characteristics of activated sludge are directly related to the operating conditions of the system from which the sludge is wasted. Therefore, the results of this study are not necessarily of general application. For this particular sludge, it was shown conclusively that approximately 75 percent of the water can be removed by gravity thickening. In a properly designed and operated gravity thickener, solids concentration can be increased from about 0.8 percent to greater than 3 percent.

Two types of centrifuges were tested on a pilot basis and one, a disc-type centrifuge, was installed as a production unit. Both types were tested at various feed rates, concentrations, and with and without

polymer addition. It was found that both types could provide a recovery of 90 percent of the feed solids and produce a cake with a solids concentration of 7.0 to 8.0 percent. Thus, sludge thickening, followed by dewatering by centrifugation, reduced the volume of sludge by approximately 90 percent. However, the moisture content of the sludge cake was still in excess of 90 percent.

Although a flash evaporator was utilized for a short period of time, sufficient data were not gathered to determine its cost effectiveness.

In order to provide a dry material suitable for use as an ingredient in poultry feed, the sludge had to be dried further. The methods utilized for sludge drying in this study were rotary kiln drying and sand bed drying. The primary problem encountered while drying the activated sludge was that the sludge is highly volatile. In general, at 600°C activated sludge is about 80 to 90 percent volatile material. The inlet temperature usually utilized in rotary kiln drying is between 600°C and 800°C (1100°F to 1400°F), while the outlet temperature is usually around 93°C (200°F). The average temperature is between these two extremes and, obviously, a portion of the sludge can be expected to volatilize. Sludge dried by the rotary kiln dryer to a moisture content of approximately 4.0 percent and sludge dried on sand beds to approximately 35 percent moisture proved to be stable and an effective poultry feed additive.

The results of the various poultry feeding studies were thoroughly discussed in Section V. The most significant conclusion from these tests was that, with the possible exception of the second chick trial, a sludge level of up to 7.5 percent in a properly formulated feed did not significantly affect poultry performance levels. The inclusion of dried sludge allowed for a reduction in other protein sources such as yellow corn and soybean meal, and also allowed for a reduction in the amount of defluorinated phosphate which had to be added to the feed. However, the amounts of animal fat and DL-methionine had to be substantially increased to maintain energy and sulfur amino acid levels.

It was found that inclusion of sludge at levels exceeding about 10 percent resulted in significant decreases in feed efficiency values and significantly lighter final body weights in the broiler chicks tested. The addition of sludge to the diet of broilers did not affect the palatability or texture of the meat.

Sludge addition to properly formulated laying hen feed did not significantly affect egg weight, egg production or feed required to produce a dozen eggs at levels up to 7.5 percent. The addition of sludge to laying hen diet provided a significant improvement in egg yolk color, but did not affect the flavor of either the yolk or albumen.

In summary, it would appear that the inclusion of sludge at a level of up to 7.5 percent in a properly formulated diet would not affect the performance or quality of poultry. In some cases, the inclusion of sludge at low levels appeared to improve performance such as by producing a slight increase in feed efficiency. The characteristic of sludge to improve egg yolk color could be significant in that the percentage of yellow corn or other color producing agents may be reduced. If the factor in the sludge which resulted in a depression in performance at sludge levels above 7.5 to 10 percent could be identified and compensated for or removed, then the percentage of sludge which could be included in the feed might be increased significantly.

PROTOTYPE DESIGN

For the purpose of determining an approximate cost of production of dried sludge for poultry feed, a prototype design based on the requirements of the WGCP is given below. The equipment for this project was, in several instances, used because of its availability. Other alternatives for sludge recovery and drying could have been used and may have been more efficient. The costs developed below assume the use of the same types of equipment as were used in this study. The equipment sizes are based on an average flow rate of 88 l/sec (2 MGD) of wastewater

containing 2,000 mg/l of BOD. It is assumed that 0.5 kg of waste activated sludge, as total solids, is produced per kilogram of influent BOD removed. Thus, the amount of sludge to be handled is 7.57 kkg/day (16,680 pounds) of dry solids. Assuming the solids concentration in the return sludge from the existing clarifier is 0.8 percent, then the daily volume of sludge to be handled is 946 M^3/day (250,000 gallons).

Sludge would be handled in this prototype system by wasting activated sludge from the return sludge line to a gravity thickener. Based on a solids loading rate of approximately 29 kg/M^2/day, the gravity thickener would be about 18 meters in diameter. The underflow solids which have a projected concentration of 3.0 percent would be pumped to a surge tank from which the thickened sludge could be fed as needed to centrifugation. Three Fletcher Sharples SST-1600 basket centrifuges would be required, as can be determined from Figure 5 which is a scale-up of actual pilot data collected at WGCP. Dewatered sludge would drop from the centrifuges to a conveyor belt and then be transferred to a rotary kiln dryer. Centrate from the centrifuges would be pumped back to the activated sludge aeration tanks. The rotary kiln dryer would be a gas fired, three pass cylindrical dryer with the capacity to evaporate 4,100 kg (9,000 lbs) of water per hour and would be equipped with a cyclone to capture fine sludge particles. It is assumed that approximately 75 percent of input solids will be recovered through the dryer. The specified equipment for this sludge recovery system is given below along with the estimated installed cost. Operating and maintenance cost estimates are presented in Table 22.

		Installed Cost
1.	Gravity Thickener (18-meter diameter)	$175,000
2.	Surge Tank (132,000 liters)	40,000
3.	Centrifuge (three 122 cm x 76 cm basket type)	210,000
4.	Rotary Kiln Dryer (4,100 kg/hr capacity)	60,000
5.	Pumps, Piping, Valves, etc.	50,000
	TOTAL	$535,000

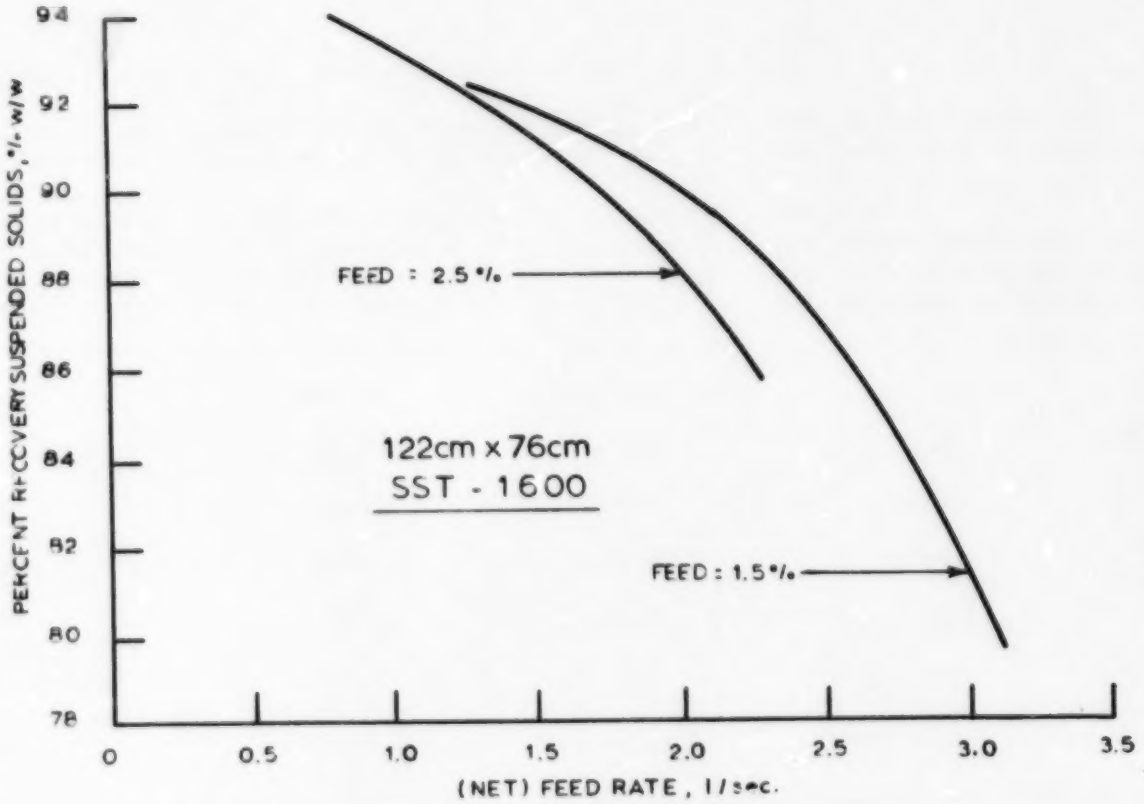

Figure 5. Percent recovery versus feed rate for a basket centrifuge (SST-1600)

Table 22. YEARLY COSTS FOR SLUDGE RECOVERY
($/year)

Item	Operation[a]	Maintenance[b]	Amortization	Total yearly cost
Gravity thickener	$ 2,100	$ 5,000	$20,600	$ 27,700
Surge tank	1,050	1,000	4,700	6,750
Centrifuges (3)	12,600	21,000	39,400[c]	73,000
Rotary kiln dryer	50,750	3,000	7,000	60,750
Pumps, piping, etc.	3,150	5,000	5,900	14,050
TOTALS	$69,650	$35,000	$77,600	$182,250

[a]It is assumed that one man is required full-time 24 hours/day, 175 days/year to operate all equipment and to perform routine maintenance and that 60 percent of all labor cost is due to the centrifuges, 10 percent is due to the dryer, 15 percent is due to the pumps, pipes, etc., 10 percent is due to the gravity thickener, and 5 percent is due to the surge tank

[b]Annual maintenance expenditures are assumed at 2.8, 2.5, 10, 5 and 10 percent of installed costs respectively for the thickener, surge tank, centrifuges, dryer, and pumps, piping, etc.

[c]Amortized over 8 years; other equipment amortized over 20 years

These cost estimates are based upon present (October 1974) prices and upon the following assumptions:

1. Maximum sludge volume to be handled is 946 M^3/day at 0.8 percent solids
2. Fuel cost = $\$0.90/10^6$ Btu
3. Dryer efficiency = 56 percent
4. Dryer yield = 75 percent of input solids
5. Operating days = 150, maintenance days = 25
6. 20-year amortization on all equipment except that the centrifuges are amortized over an 8-year period
7. 10 percent interest on borrowed money
8. Labor required is 24 man-hours/day at $5/hour

ECONOMIC ANALYSIS

At this point, two significant facts have been established; one is that it is technically feasible to recover waste activated sludge and, second, the recovered sludge has value as a poultry feed ingredient. The final point to be discussed is whether or not it is economically feasible to recover the sludge for use as a chicken feed.

In any activated sludge system, waste sludge must be handled in some manner. If one assumes that the system described here—i.e., gravity thickening followed by centrifugation--is as cost effective a method to dewater sludge as any other method available, then the cost of dewatering sludge to a solids concentration of 8.0 percent can be calculated. Assuming a 90 percent yield through the centrifuges, the daily production of dewatered sludge is 6.8 kkg (7.5 tons) on a dry weight basis. From Table 22, the total yearly cost for dewatering is $121,500 which is equivalent to $119/kkg ($108/ton). This cost is assumed to be incurred whether the dewatered sludge is subsequently utilized as chicken feed or is disposed of by landfill. The actual cost to produce dried sludge for chicken feed therefore, is assumed not to be the total cost of sludge disposal, but only the cost of sludge drying beyond 8.0 percent. From Table 22, the

total yearly cost associated with sludge drying is approximately $60,750. Assuming 75 percent recovery of input solids through the dryer, the daily production of dried sludge would be 5,112 kg (11,259 lbs). The unit cost of dried sludge then would be about $79/kkg ($72/ton).

In order to determine the value of the dried sludge, one must consider the value of the feed ingredients which are no longer required because of the addition of the sludge. For this purpose, the composition of feed shown in Table 23 is assumed to be a typical diet. Also shown in Table 23 is the composition of a feed which contains 7.5 percent dried activated sludge which is the maximum sludge level used with success in the poultry feeding studies. Table 24 gives estimated unit costs for the ingredients in the diets which are affected by the addition of sludge.[14]

Table 23. COMPOSITION OF FEED
(percent)

Ingredient	Basal	7.5% sludge	Change
Yellow corn	54.97	51.55	-3.42
Soybean meal (48.5%)	36.50	31.08	-5.42
Alfalfa meal (20%)	2.50	2.50	-
Citrus sludge	0.00	7.50	+7.50
Ground limestone (38% Ca)	0.74	0.86	+0.12
Defluorinated phosphate (18% P and 32% Ca)	2.11	1.67	-0.44
Iodized salt	0.40	0.40	-
Vitamin pre-mix	0.50	0.50	-
Animal fat	2.15	3.78	+1.63
DL-Methionine	0.13	0.17	+0.04

Thus, from Table 23 it can be seen that a reduction of 3.42 percent in the amount of yellow corn required results from the addition of the dried sludge. The value of the yellow corn which is saved is about $4.92/kkg

Table 24. CHANGES IN INGREDIENT COSTS RESULTING FROM SLUDGE ADDITION

Ingredient	Unit cost[a]	$/kkg	% Change[b]	Savings or cost/kkg
Yellow corn	$3.66/bushel	$ 144	+3.42	+$4.92
Soybean meal	$170/kkg	$ 170	+5.42	+$9.21
Ground limestone	$1.80/100 kg	$ 18	-0.12	-$0.02
Defluorinated phosphate	$176/kkg	$ 176	+0.44	+$0.77
Animal fat	$0.34/kg	$ 341	-1.63	-$5.56
DL-Methionine	$3.30/kg	$3,300	-0.04	-$1.32
			FEED INGREDIENT SAVINGS	+$8.00
Dried activated sludge	$79/kkg	$ 79	-7.50	-$5.92
			ACTUAL SAVINGS IN FEED COSTS	+$2.08

[a]Unit costs are from Feedstuffs[14] for November 1974, F.O.B. Atlanta or nearest market to Winter Garden, Florida

[b]From Table 23

of feed. By similarly calculating the value of the ingredients which are no longer required and subtracting the value of the ingredients which must be added, a resultant savings of $2.08/kkg ($1.89/ton) of feed is obtained as shown in Table 24.

The savings in feed ingredient costs may be interpreted to be the value of the dried sludge as a feed ingredient. For the feed composition shown, the addition of 7.5 percent sludge, or 75 kg of sludge per kkg of feed, results in a savings of $8.00/kkg in feed ingredients and the value of the added sludge is then $107/kkg ($97/ton). The cost of drying the sludge is $79/kkg ($72/ton) of dried sludge F.O.B. the citrus plant, which results in an apparent profit of $28/kkg ($25/ton) of dried sludge. Thus, recovering the sludge for poultry feed results in a net profit whereas ultimate disposal of the sludge cake by landfilling would cost an additional $6/kkg ($5.45/ton).

In summary, it would appear that the recovery of activated sludge for subsequent use as an animal feed material is both technically feasible and economically attractive. Even if the total cost of dewatering and drying of sludge is considered rather than just the cost of drying, it is apparent that the recovery of sludge for poultry feed could significantly off-set the cost of sludge handling. The total cost of handling sludge by thickening, centrifuging and hauling to landfill for ultimate disposal is $125/kkg ($113/ton), whereas the net cost for recovering the sludge as poultry feed is $91/kkg ($83/ton). This is a reduction in sludge handling costs of 27 percent.

It should be noted that the above economic analysis is based on one given set of conditions and assumptions. The cost of capital equipment, labor, fuel and feed ingredients will vary widely with location and market conditions. It should also be noted that the cost of sludge recovery would be substantially reduced for an industry which operated year round rather than on a seasonal basis, as equipment would be utilized continuously, increasing the yearly production of dried sludge by a factor of 2.4.

The total yearly costs would be increased by a factor of only 1.5 The result is a net decrease in the unit cost of sludge recovered of approximately 38 percent.

SECTION VII

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